ACCIDENTS WAITING TO HAPPEN
BLADE STRIKES

Putting a moving part in close proximity to a non-moving part is the source of many an engineering problem. It is especially true in the helicopter business where there is good motivation for making the aircraft as compact as possible.

Hub-fuselage proximity

A requirement in both the UTTAS and AAH design competitions that eventually resulted in the Black Hawk and the Apache was that two could be transported in a Lockheed C-141 airplane, and then prepared for flight in two hours or less. The C-141 has an eight-foot high cargo area.

Sikorsky and Boeing competed for UTTAS, and Hughes and Bell squared off for the AAH. Each used a "kneeling" landing gear to minimize the helicopter’s height and all but Bell located the rotors low and close to the fuselage. (Bell designed an ingenious scheme for telescoping the mast into the transmission of their AH-63.)

Too close for comfort

The three companies who placed their rotors close to the fuselage all encountered difficulty. Both UTTAS prototypes were plagued by high vibration, which at least partially came from blade loads induced by the upflow of the air over the front of the fuselage.

Both Sikorsky and Boeing raised their rotors by lengthening the rotor mast. They thus minimized the upflow effects, but also made it necessary to remove the rotor and transmission for C-141 transport. The Black Hawk first flown thus appeared different from the one finally delivered to the Army.

That the Apache did not suffer from high vibration from this source was probably due to its much narrower forward fuselage. It was

Rotor Positions On The UH-60 Black Hawk

Initial Design

Final Design

found however, that when initiating a pushover maneuver, the Apache’s blades came down over the nose far enough to graze the canopy’s top.

To cure this unacceptable situation, the mast was lengthened first by 10 inches, and then after further testing by another six inches. This change, shown on the next page, forces a disassembly for transport in a C-141 (but not in the larger C-5).

A benefit of raising the rotors on each of these helicopters was the reduced cockpit noise due to "canopy drumming" as the blades pass over.

Rotor Positions On The AH-64 Apache

Blade clearance

Hinged, flexible blades are free to bend and to flap. Centrifugal forces tend to keep them straight and in a position nearly perpendicular to the shaft, but there are other aerodynamic and dynamic forces that want to bend and move the blades. Regarding clearance between the blades and the airframe, these forces can create a critical situation when the helicopter contacts the ground either firmly or during a run-on landing.

In flight, the moments that accompany blade flapping will tend to move the helicopter out of the rotor's way (not always fast enough). But on the ground, the helicopter has no way to escape. So, when the rotor is up to full operating speed, inadvertent cyclic-pitch-control inputs may cause the blades to strike the fuselage. This can also happen at low rotor speeds as well, if a gust or the wake from a nearby helicopter induces high flapping.

Appropriate cyclic pitch

The amount of forward cyclic pitch designed into the control system depends primarily on the helicopter's high-speed goal. It must be enough pitch to trim the rotor aerodynamically at the maximum speed with some margin for maneuvering. The rearward cyclic pitch must be enough to trim in rearward flight and/or to make a nose-up flare for a quick stop or autorotational landing.

A survey of existing helicopters indicates a range from 20° forward cyclic pitch to 15° aft pitch. When sitting on the ground, rotor flapping will be equal to these angles if the pilot inadvertently moves his cyclic stick to the stops.

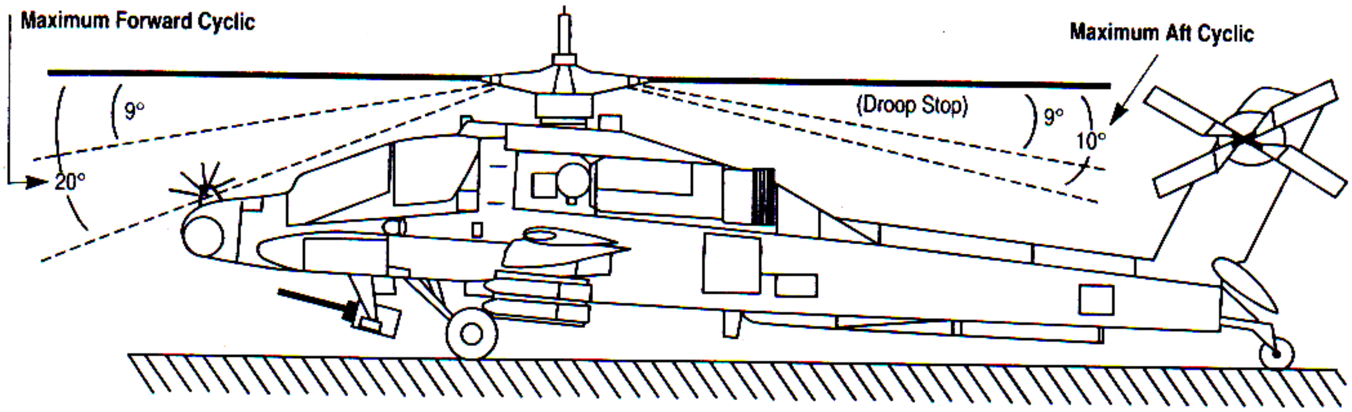
Most rotors are designed with "droop stops" that hold the blades up when the rotor is not turning. But being close to the hinges, they are relatively ineffective against the large aerodynamic forces acting on the blade's outboard portion. So the blade will bend around the stop almost as if it were not there.

Therefore to be absolutely safe, the clearance angles for fore and aft blade flapping should be at least as large as the fore and aft cyclic-pitch angles.

In the past, this rule-of-thumb has not generally been observed on the assumption that no pilot would inadvertently use full cyclic pitch on the ground. Pilots have, however, and several cases of both fore and aft blade strikes have been attributed to this cause.

The Apache has 20° of forward cyclic pitch. Although seldom used in flight, enough forward cyclic pitch was inadvertently imposed during two ground incidents to make the blade flap down over the nose and contact the sight for the pilot's night vision system. The problem is illustrated below.

Full Forward Cyclic Striking The Apache's PNVS



Tail-boom strikes

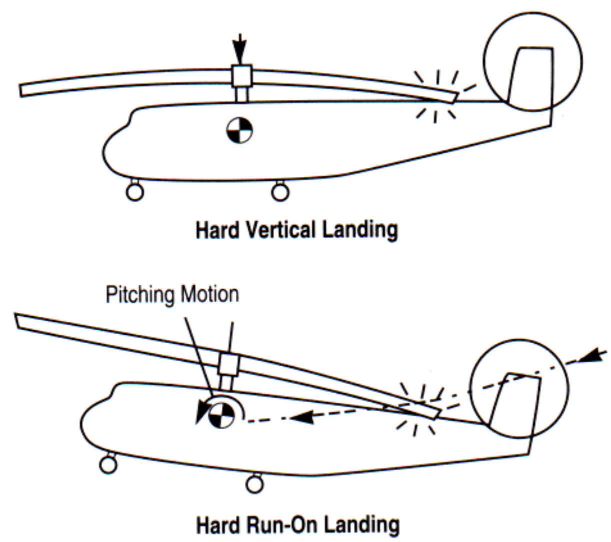
Chopping off the tail boom with a blade is an all-too-frequent occurrence. Most often this type of accident happens as the helicopter makes a hard vertical touchdown or a run-on landing following autorotation. There are two contributing factors in these accidents. The blades keep on coming down even after the fuselage has stopped, and the sudden nosedown motion following the contact of aft-mounted wheels or the back of skids makes the pilot naturally want to pull the stick back to counteract it. The possible results are shown in the figure.

Designing the landing gear to have a long energy-absorbing stroke may alleviate these landing problems.

Redesign it

To counteract these tail-boom strikes, designers have sometimes been forced to redesign the tail boom. An example of such a redesign was the Sikorsky S-55 (H-19), which originally had the tail boom coming straight out of the main fuselage. After a series of accidents, it was redesigned with the tail boom angled down 3^{o} as illustrated by the photographs on the next page.

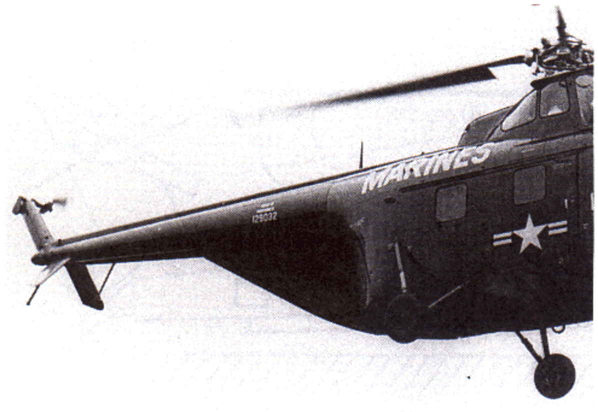
Hard Landings Invite Tail-Boom Strikes



In flight too

Tail boom strikes have also happened in flight. The most common scenario is that during the entry to autorotation as the collective pitch is lowered, the rotor flaps forward since the advancing blade sees a greater reduction in lift than the retreating blade. The pilot overreacts to the sudden nosedown pitching moment by suddenly pulling the cyclic stick back. With this action, the rotor flaps back, but the tail boom is still rising because of the initial

Sikorsky S-55 (H-19) Tail-Boom Angles



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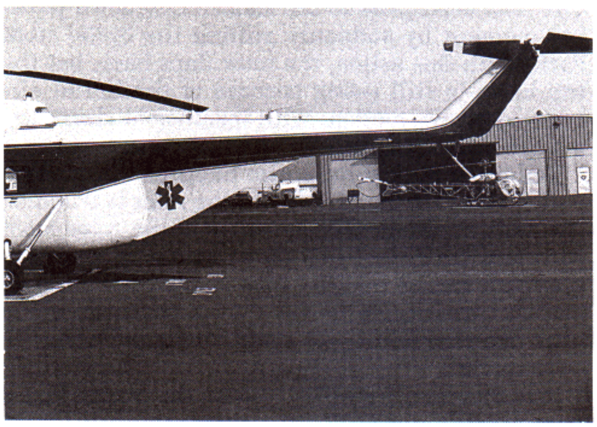

Revised

aircraft-nosedown motion. With insufficient clearance, a blade strike results.

Tail-boom strikes have also happened in maneuvering flight. In forward flight, the rotor is trimmed out approximately perpendicular to the rotor mast with forward cyclic pitch. The amount of rear flapping that can be induced with sudden full-aft stick motion corresponds to the sum of this trim value of forward cyclic plus the maximum aft cyclic designed into the swashplate.

It is therefore possible to make the blades flap a surprising amount down toward the tail boom. Slow cyclic-stick pulls will not get the pilot into trouble because the noseup moment applied to the helicopter by aft flapping will tend to move the tail boom down out of the way.

Other incidents

Flapping to the limits of lateral cyclic pitch (usually not more than 10^{o}) generally will not cause a blade strike unless the helicopter is equipped with long wings. But for rotors with large hinge offsets, too much lateral flapping may cause the helicopter to roll over on the ground. To guard against this type of accident, some helicopters are equipped with stick locks, which are either manually engaged or automatically activated through mechanisms that sense landing-gear compression.

Problems just getting started

Another scenario involves gusts, which are generally less of a factor than cyclic pitch when the rotor is up to full speed. But at low speeds--during startup or shutdown--gusts are of concern since the blade is free to flap and bend in the absence of the stiffening effects of strong centrifugal forces.

For very low rotor speeds, the aerodynamic forces are much less than at full rotor speed and the droop stops are of some value. Many rotors have spring-loaded, centrifugally operated droop stops that prevent the blades from going below the rotor hub's height until the rotor speed is near its operating value.

Despite this there have been incidents of tail boom strikes during startups and shutdowns in a high wind or when another helicopter was landing or even taxiing nearby. The U.S. Army requires that the rotor can be safely started and stopped in 45-knot winds, while the U.S. Navy requires a 60- knot capability.

Even while parked, rotor blades may want to fly. At least one incident occurred when one helicopter landed beside another. The recirculating rotor wake lifted the parked helicopter's blade, which then suddenly dropped against its droop stop leaving a permanent bend about two-thirds the way out. To guard against this possibility, the designer should provide some means of tying the blades down or quickly folding and stowing them after landing.

Tail rotors too

The tail rotor does not have a cyclic-pitch system that makes it flap more than the designers allowed for, but it does flap or teeter in response to collective pitch, sideslip, and yaw rate. Unlike the main rotor in flight, the tail rotor cannot move the tail boom out of the way as it flaps and so tail rotors mounted on a too-short shaft have flapped enough to strike a tail boom or fin during rapid pedal inputs at high speeds.

To guard against this possibility, the designer of a new helicopter should enlist the help of an aerodynamicist who can estimate the maximum tail rotor flapping under the worst possible conditions.

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